

**DRAFT**

## **Smoky Canyon Mine RI/FS**

### **Pilot Study Report**

### **Semi-Passive Biological Treatment Technology – Seep DS-7**

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## LIST OF ACRONYMS

°C	Degrees Celsius
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CO	Consent Order
COPC	Chemical of Potential Concern
DQO	Data Quality Objective
EPA	United States Environmental Protection Agency
FBR	Fluidized Bed Bioreactor
gpm	gallons per minute
H <sub>2</sub> S	Hydrogen Sulfide
H <sub>2</sub> Se	Hydrogen Selenide
IDEQ	Idaho Department of Environmental Quality
lbs	pounds
mg/L	milligrams per liter
ODA	Overburden Disposal Area
PVC	Polyvinyl Chloride
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation/Feasibility Study
SAP	Sampling and Analysis Plan
Se <sup>0</sup>	Selenium (elemental)
Se <sup>+4</sup>	Selenite
Se <sup>+6</sup>	Selenate
SOW	Statement of Work
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
USFS	United States Department of Agriculture Forest Service

## 1.0 INTRODUCTION

The purpose of this report is to describe the results of a water treatment pilot study conducted by the J.R. Simplot Company (Simplot) using a semi-passive biological treatment process developed by the University of Idaho (Möller 2002). The study was performed at the Smoky Canyon Mine at seep DS-7, which flows from the Panel D external overburden disposal area (ODA), from July 2013 to November 2015 with final data collection of the bioreactor materials in June 2016.

### 1.1 Background Information

Simplot operates the Smoky Canyon Phosphate Mine in southeastern Idaho (Figure 1-1). The Smoky Canyon Mine (the Site) is the subject of a 2009 Administrative Settlement Agreement and Order on Consent/Consent Order (Settlement Agreement/CO) for performance of a Remedial Investigation/Feasibility Study (RI/FS) entered into by the United States Department of Agriculture Forest Service (USFS), United States Environmental Protection Agency (EPA), Idaho Department of Environmental Quality (IDEQ), and Simplot (USFS, EPA, and IDEQ 2009), pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). The Settlement Agreement/CO, and its accompanying Statement of Work (SOW), provide a mechanism to investigate the environmental effects of phosphate mining and milling operations and develop remedies to address environmental conditions that represent a risk to human health or the environment.

The RI Report (Formation 2014a) identified elevated selenium concentrations in certain surface waters downstream of mining-disturbed areas including lower Pole Canyon Creek, Hoopes Spring, South Fork Sage Creek, and lower Sage Creek. Elevated concentrations of selenium and other chemicals of potential concern (COPCs) were also observed in several seeps emanating from external ODAs. Overburden disposed in backfilled pits and in external ODAs is the source of selenium (and other COPCs) to the environment. The COPCs are derived from sulfides and organic matter in mudstone and middle waste shale of the Meade Peak Member of the Phosphoria Formation. Release of COPCs from overburden occurs through physical and chemical weathering processes. The primary pathway for transport of selenium from source areas is in Wells Formation groundwater. This groundwater discharges to surface water flow at Hoopes Spring and South Fork Sage Creek springs.

Remedial actions, which may include water treatment, will be implemented to reduce selenium concentrations in Hoopes Spring, South Fork Sage Creek, and lower Sage Creek. The target reductions in selenium concentrations will ultimately depend on final remedial action objectives established for the Site (e.g., Idaho surface water quality standards, site-specific standards,

etc.). Hoopes Spring represents a relatively low-selenium-concentration (i.e., typically <0.13 milligrams per liter [mg/L]), high-flow treatment candidate. South Fork Sage Creek springs discharge at numerous locations, some of which are relatively low-selenium (<0.09 mg/L) and moderate- to low-flow (<150 gallons per minute [gpm]) treatment candidates. At both of these spring complexes, treated water would be returned to streams that support aquatic life. In contrast, seeps such as DS-7 represent relatively high-selenium-concentration (up to 9 mg/L), low-flow (<4 gpm) treatment candidates. Treated seep water would not necessarily be discharged to regulated streams supporting aquatic life.

Simplot prepared a Treatability Study Technical Memorandum that identified a range of candidate water-treatment technologies for selenium removal potentially suitable for implementation at the Site (NewFields 2009). Pilot-scale treatability tests of several of these technologies have been conducted including a semi-passive subsurface bioreactor treatment system at seep DS-7 by the University of Idaho in 2001 (Möller 2002) (refer to Section 2.2.1), an ABMet<sup>®</sup> active biological reduction treatment system at seep DS-7 in 2009 (GE 2010, Formation 2010) (refer to Section 2.2.2), a reverse osmosis treatment system at Hoopes Spring in 2010 (Formation 2011a), and a zero-valent iron treatment technology at South Fork Sage Creek springs from 2009 to 2011 (Formation 2012). Of these treatment technologies, reverse osmosis and active biological treatment are effective for decreasing selenium concentrations to ranges that could be discharged to area surface water, semi-passive biological treatment may be effective for decreasing selenium concentrations in seeps that do not discharge to surface water, and zero-valent iron treatment is not effective for meeting Site objectives.

Currently, the first phase of a pilot study is underway to test an active biological treatment technology using a fluidized bed bioreactor (FBR) (Formation 2014b). The FBR facility was constructed in 2014 between Hoopes Spring and South Fork Sage Creek springs to treat a portion of the groundwater discharging from these springs. Utilization of FBRs for selenium treatment is a developing approach for biological treatment, potentially yielding higher kinetics in a smaller footprint. The current system has a capacity of 250 gpm. Phase 2 is currently under construction, and will involve increasing the treatment capacity to process additional water collected from South Fork Sage Creek springs and Hoopes Spring. An ultra-filtration/reverse osmosis system, in concert with additional FBR capacity, will be installed in the water treatment building to increase the capacity to approximately 2,000 gpm, and is scheduled to be operational in 2017.

Because the duration of the original 2001 semi-passive biological selenium removal pilot study at seep DS-7 was only 7 months and because the pilot unit bioreactors remained in place, a second pilot study was planned at the seep to evaluate the effectiveness of the treatment system over a longer period of time through seasonal changes using other nutrients. Seep DS-7 discharges to the surface at the eastern toe of the Panel D external ODA. Overburden material comprising this ODA was placed directly overlying a small stream channel during mining of Panel D from 1993 through 1998 (Formation 2014a). The ODA was covered with a partial

topsoil and vegetative cover system in 2002. Seep DS-7 is likely the surface expression of water that infiltrates the ODA, reaches the lower permeability material present at the ground surface beneath the ODA, and flows along the small channel. The seep is captured by detention basin DP-7 where the water either evaporates or infiltrates downward into underlying Wells Formation bedrock. As mentioned above, DS-7 is a relatively low-flow high-selenium-concentration seep.

The Final Pilot Study Work Plan and Sampling and Analysis Plan (SAP) (Pilot Study Work Plan/SAP) for the semi-passive biological treatment technology pilot study at seep DS-7 (Formation 2011b) describes the pilot study design, data quality objectives (DQOs), roles and responsibilities, and data analysis and reporting requirements. The SAP describes field measurements for system optimization, sample collection for performance monitoring, quality assurance/quality control (QA/QC) procedures, and related data review and documentation procedures. Implementation of the pilot study began in July 2013 and monitoring and maintenance of the system continued through November 2015; final samples of the bioreactor materials were collected in June 2016. This pilot study report details the objectives, procedures, and results of the pilot study.

## 1.2 Pilot Study Objectives

The purpose of this pilot study was to evaluate the effectiveness, implementability, and cost of the semi-passive biological treatment technology for removing selenium from seep water while producing manageable effluent and process-waste streams.

The specific objectives of this pilot study were to:

- Evaluate the effectiveness of the semi-passive biological system for removing selenium;
- Determine operating parameters to provide additional information regarding implementability and cost of the system; and
- Assess the applicability of the technology in contributing to achievement of remedial action objectives eventually developed for this Site.

Although the primary purpose of this pilot study was to evaluate selenium removal, data were also collected to evaluate the effectiveness of the semi-passive biological treatment process for removing other COPCs and these data are available for consideration during development and evaluation of remedial alternatives in the FS.

### 1.3 Report Organization

This report is organized into the following sections:

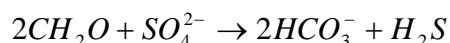
- Section 2: Supporting Information – presents an overview of the biological treatment technology, summarizes previous pilot studies, describes the setting of seep DS-7, and summarizes historical water quality and flow data.
- Section 3: Pilot Study Design and Implementation – describes the infrastructure of the semi-passive treatment system implemented at seep DS-7 and discusses system operation and maintenance, monitoring, treatment byproducts, and deviations from the Pilot Study Work Plan/SAP.
- Section 4: Pilot Study Results – presents DQOs from the Pilot Study Work Plan/SAP; evaluates field and laboratory data quality; presents results of the initial startup and operational phases of the pilot study; characterizes and assesses treatment byproducts; and summarizes operation and maintenance parameters, influent and effluent water quality, and selenium removal.
- Section 5: Summary and Conclusions – summarizes the effectiveness and implementability of the semi-passive treatment system, provides an estimate of capital and operation and maintenance costs, and presents conclusions based on the pilot study results.
- Section 6: References – lists references cited in this report.

## 2.0 SUPPORTING INFORMATION

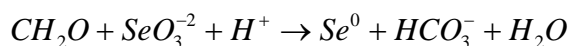
Biologically-based selenium treatment technologies use bacteria, algae, and/or aquatic plants to remove selenium from impacted water. Biological reduction systems have been implemented as active, semi-passive, and passive treatment systems. A key difference between active and passive systems is the amount of operator control over parameters such as water temperature, pH, carbon addition rates, and oxygen concentration. The following subsections provide a technology overview, descriptions of previous biological treatment pilot studies conducted at seep DS-7, and historical water quality and flow data for the seep.

### 2.1 Overview of Treatment Technology

Removal of selenium from water can be achieved by decreasing the solubility of the selenium ions and compounds via biological processes. There are numerous species of bacteria that can use sulfur instead of oxygen for cellular respiration. The chemical reaction that describes the bacterial reduction process from sulfate to sulfide is shown below:

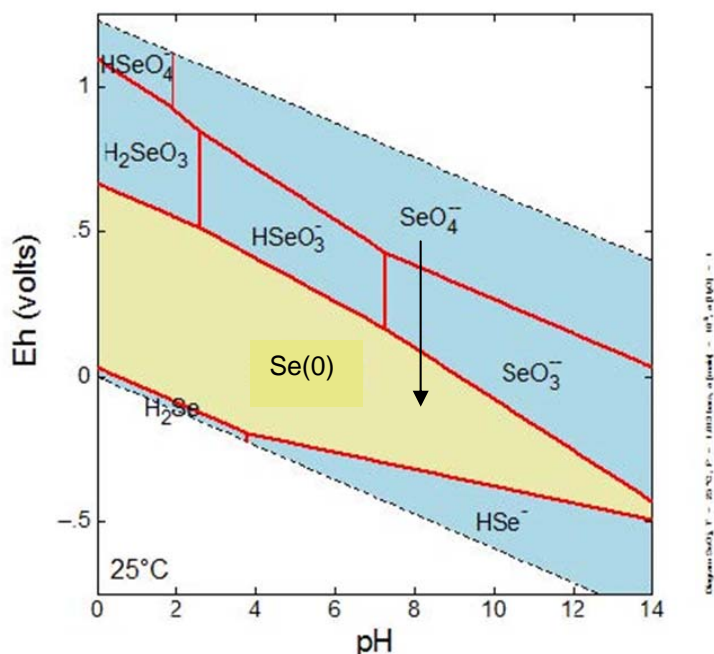


Some sulfate-reducing bacteria have the ability to also reduce selenium, resulting in a change of the oxidation state of the metalloid during the respiration process. This process converts selenate ( $Se^{+6}$  or  $SeO_4^{-2}$ ) to selenite ( $Se^{+4}$  or  $SeO_3^{-2}$ ) and then to elemental selenium ( $Se^0$ ) as shown in the following equation:



The respiration process can be depicted by a vertical line (or Eh reduction) on an Eh-pH diagram for selenium (Figure 2-1). Ideal operating conditions will reduce the selenate or selenite to elemental selenium while not becoming so reducing as to produce hydrogen selenide ( $H_2Se$ ) or hydrogen sulfide ( $H_2S$ ).

Biological selenium reduction treatment systems use bioreactors filled with activated carbon, plastic bio-rings, or other media maintained under anaerobic conditions (i.e., lack of oxygen and reducing conditions) to encourage selenium reducing bacteria to colonize and metabolize the selenium compounds in the treatment flow.



**Figure 2-1. Eh-pH Diagram for Selenium.**

Note: The biological respiration process can be approximated by a vertical reaction path (arrow).

In semi-passive systems, the bioreactors are typically filled with an inert medium, and are dosed manually with nutrients and organic carbon to sustain the bacteria and maintain anaerobic conditions. In active systems, the optimum conditions (pH, oxidation-reduction potential, dissolved oxygen, temperature, etc.) are maintained at set levels using inline monitoring, with controlled, continuous dosing of feed chemicals to maintain optimum growth and reducing conditions within the bioreactor vessels. In addition, active systems are backwashed on regular cycles to prevent fouling and short circuiting due to mineral deposition, precipitation products, or cellular byproducts. In contrast, solids are allowed to build up in semi-passive systems, and the entire medium is changed out when it reaches saturation (as indicated by monitoring the effluent for break-through).

## 2.2 Previous Biological Treatment Pilot Studies at Seep DS-7

Two separate biological treatment pilot studies have been conducted at seep DS-7. The first study was performed by the University of Idaho in 2001 (Möller 2002). The second study was performed under the RI/FS Settlement Agreement/CO by ABMet® in 2009 (GE 2010). Both studies used two bioreactor vessels operated in series to treat water from seep DS-7.

### 2.2.1 Semi-Passive Biological Treatment Pilot Study

The University of Idaho semi-passive biological treatment system was set up at seep DS-7 and operated from May to November 2001 (Möller 2002). Water was diverted from a small impoundment downstream of the seep to a nearby holding tank via a collection pipeline. Water flowed from the holding tank to two 2,000-gallon octagonal, ribbed, polyethylene bioreactor vessels at an initial influent flow rate of 0.5 gpm. Access to the system was via manholes in the vessels. Bioreactors were dosed with nutrients, as needed, through the manholes. Ports were installed at the inlet and outlet for sampling purposes.

The bioreactor vessels were filled with polyethylene packing rings for the bacterial colonies to grow on. Sediment/soil from the channel of the seep was used as a substrate to culture selenium-reducing bacteria in the laboratory, and the bioreactor vessels were each inoculated with approximately 100 pounds of substrate. The vessels were dosed with cheese whey (a nutrient source for the bacteria) and elemental iron (to aid in the reduction and precipitation of  $\text{Se}^0$ ). The cheese whey provided most of the nutrients that the bacteria needed to flourish, but, because of the liquid form, had to be added to the bioreactors on a semi-continuous basis. After three months, the organic substrate and nutrient source was changed to solid organic compost.

In this study, removal of selenium increased significantly after the nutrient source for the treatment system was changed from liquid cheese whey to organic compost. The initial result achieved was 75 percent selenium removal. The best result achieved was 97 percent removal in November 2001 just before the system was shut down (Möller 2002).

### 2.2.2 Active Biological Treatment Pilot Study

The ABMet<sup>®</sup> active biological treatment system was set up along the main haul road above seep DS-7 and operated from September through October 2009 (Formation 2010). A shallow sump was excavated adjacent to the seep, a pump was installed, and seep water was pumped uphill at rates of 3 to 5 gpm from the sump via a pipeline to the pilot unit. Once the water reached the pilot unit, 1 to 2 gpm of seep water was diverted into the treatment system and the remaining water was returned to the seep area via gravity flow through another pipeline. The relatively long conveyance from the seep to the treatment system resulted in diurnal variations in influent water characteristics (temperature, pH, oxidation-reduction potential, and dissolved oxygen). The pumping rate was adjusted to match the rate of seep inflow to the sump, which allowed pumping of seep water up to the pilot unit in freezing temperatures until the study was terminated in late October.

The main bioreactors consisted of two cells mounted on a skid and filled with granular activated carbon. Bacteria were seeded in the bioreactor cells to form a bio film. The ABMet<sup>®</sup> pilot system used a molasses-based substance as an organic substrate and nutrient source. The system

operated at an initial flow rate of 1 gpm, but flow was increased to 2 gpm to test the effectiveness at shorter retention times. The ABMet<sup>®</sup> system was an active system with metered dosing of organic substrate and nutrients (based on feedback control loops for pH and oxidation-reduction potential) (Formation 2010). Degassing was performed each week to release gas pockets trapped in the bioreactor bed. Precipitated metals, excess biomass, and suspended solids in the influent water were retained in the bioreactor media. Backwashing was performed at the end of the pilot test to remove these solids.

The ABMet<sup>®</sup> pilot study had higher removal rates (>99 percent) than the University of Idaho study, which is consistent with expectations for active systems versus semi-passive systems. Concentrations of antimony, arsenic, cadmium, copper, molybdenum, nickel, uranium, vanadium, and zinc were also decreased in the effluent. However, concentrations of ammonia, total alkalinity, bicarbonate, chloride, phosphorus, potassium, and total organic carbon increased. On the basis of these results, additional polishing of the treated water would likely be necessary before the effluent could be discharged to nearby streams (Formation 2010).

### **2.3 Seep DS-7 Setting and Historical Water Quality and Flow Data**

From 1993 through 1998, a portion of the overburden material originating from mining in the Panel D pits was placed in the Panel D external ODA, directly overlying a small stream channel (Figure 2-2). After mining, the western portion of the ODA was covered with topsoil and chert and seeded, and the eastern portion of the ODA was directly seeded (Formation 2014a). Seep DS-7 currently flows from the eastern toe of the ODA downstream into detention basin DP-7. From the detention basin the water either evaporates or infiltrates into Wells Formation bedrock. Photographs of the seep and treatment system are provided in Appendix A. Refer to Photos A-1 through A-3 for the location and setting of seep DS-7, detention basin DP-7, and the pilot treatment system influent and effluent sampling locations.

Flow measurements are collected at the DS-7 flume (Photo A-4) on a semiannual basis during spring runoff (high-flow) and fall low-flow conditions. Spring high-flow measurements have historically ranged from about 4 to 40 gpm. Fall low-flow measurements have ranged from 0.4 to 4 gpm. Flow measurements are typically collected concurrently with water quality samples.

Surface water monitoring was conducted at seep DS-7 from 2001 through mid-2013, prior to implementation of this pilot study. Total selenium concentrations ranged from 0.27 to 8.6 mg/L with an average concentration of 2.5 mg/L (Table 2-1). These concentrations are consistent with influent concentrations reported during the previous pilot studies performed at seep DS-7. Selenium concentrations generally vary seasonally, with relatively higher concentrations occurring during spring high-flow sampling events, and lower concentrations occurring during fall low-flow sampling events.

### 3.0 PILOT STUDY DESIGN AND IMPLEMENTATION

The semi-passive biological treatment system for this pilot study was located approximately 400 feet downgradient from seep DS-7, and 100 feet upgradient of detention basin DP-7 (Figure 2-2). Influent water was collected from the seep and effluent water was discharged from the treatment system upgradient of DP-7, with much of the flow entering the detention basin. The pilot unit operated for almost three years to evaluate selenium removal efficiency under various seasonal conditions. Influent flows to the pilot system ranged from 0.5 to 3.3 gpm.

As described in Section 1.2, the objectives of the pilot study were to evaluate the effectiveness of the semi-passive biological treatment system for removing selenium while producing manageable effluent and process-waste streams, determine operating parameters to provide additional information regarding implementability and cost of the treatment system, and assess the applicability of the technology in contributing to achievement of remedial action objectives developed for the Site.

The types of data that were collected to support these objectives were:

- Operation and maintenance parameters (including during the winter season);
- Treated water quality;
- Generation rate and characteristics of any treatment byproducts; and
- Capital and operating costs.

The following subsections describe the infrastructure of the semi-passive treatment system, operation and maintenance required during the pilot study, monitoring performed, treatment byproducts produced, and deviations from the Pilot Study Work Plan/SAP (Formation 2011b).

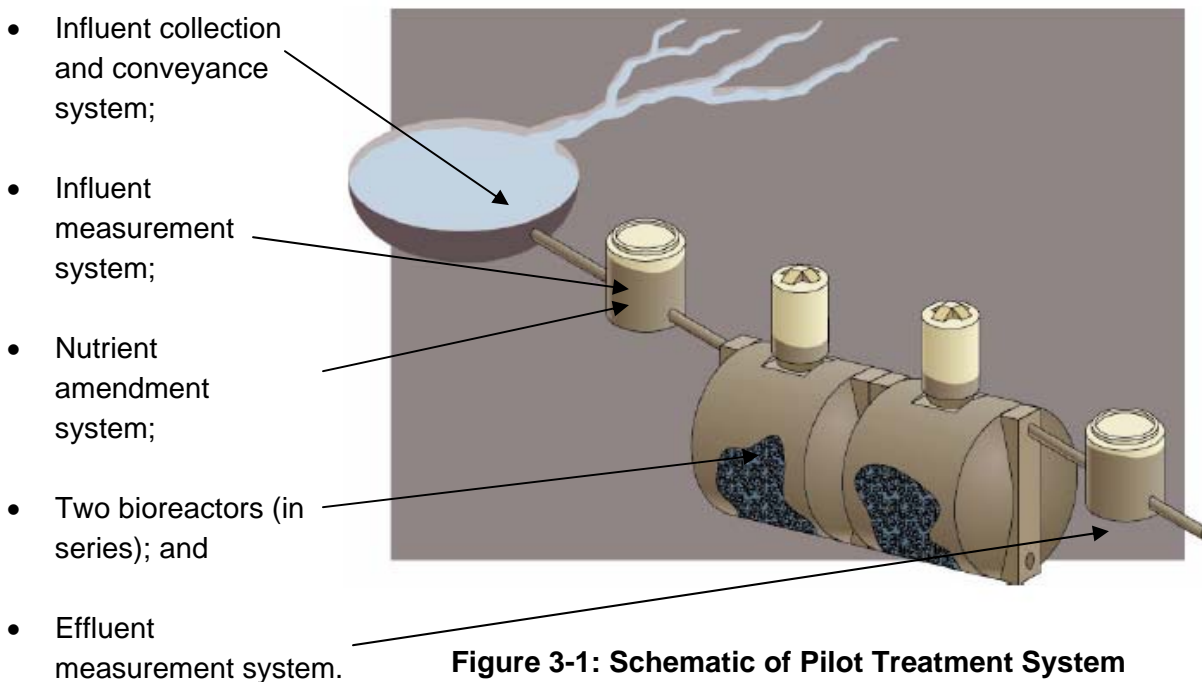
#### 3.1 Treatment System Infrastructure

Many of the components of the pilot treatment system were already in place from the previous pilot studies (refer to Sections 2.2.1 and 2.2.2). Seep water was collected in a small pond and gravity-fed to a nearby holding tank via a collection pipeline. Water flowed from the holding tank to two 2,000-gallon polyethylene bioreactor vessels, located approximately 250 feet away. The bioreactors, holding tank, and collection pipeline were buried 3 feet below the ground surface to prevent freezing. An overflow line near the top of the holding tank returned excess flow back to the channel of the original seep. Bioreactors were equipped with manhole access for dosing the vessels with nutrients as needed. Ports were installed at the inlet and outlet for sampling purposes. Photo A-5 (Appendix A), taken during the summer, shows the influent manhole and

the manhole above the first bioreactor. Photo A-6, taken during the winter, shows both the influent and effluent manholes and the manholes above the bioreactor vessels.

Components of the existing treatment system were evaluated in June 2011 to determine if they were usable for this pilot study. The bioreactors and influent and effluent measurement systems were usable; however, the system was cleaned, the collection and conveyance system was replaced, and measurement systems (flumes) were installed.

The pilot study treatment system consisted of the following major components (Figure 3-1), as described below:



**Figure 3-1: Schematic of Pilot Treatment System**

### 3.1.1 Inflow Collection and Conveyance

Water was collected from seep DS-7 via a screened inlet pipe within the seep area. The existing collection system, which was used during the ABMet® treatability study (refer to Section 2.2.2) and consisted of a partially submerged polyethylene tank, was used to protect the screened inlet pipe from sediment buildup and potential clogging or fouling. The new conveyance pipe, constructed of 2-inch polyvinyl chloride (PVC), was buried to prevent freezing. A metering valve was installed near where the pipe discharged to the pilot study treatment unit to adjust the influent flow rate as needed. The flow rate during the study was typically maintained at 1 gpm.

### 3.1.2 Influent and Effluent Measurement Systems

The influent and effluent measurement systems consisted of trapezoidal flumes installed below the ground surface within each manhole (Appendix A, Photos A-7 and A-10). Sondes for continuous monitoring of water temperature, specific conductance, dissolved oxygen, pH, oxidation-reduction potential, turbidity, and total dissolved solids (TDS) were installed in the influent and effluent stilling wells.

Pressure transducers and data-loggers were installed within the flumes to monitor flow continuously. Telemetry was set up at the inlet and outlet in July 2013 to enable remote tracking of influent and effluent data. Shortly thereafter, an apparent lightning strike damaged the inlet telemetry equipment. The equipment was shipped back to the vendor for repairs and reinstalled upon return.

### 3.1.3 Organic Substrate and Nutrient Amendment System

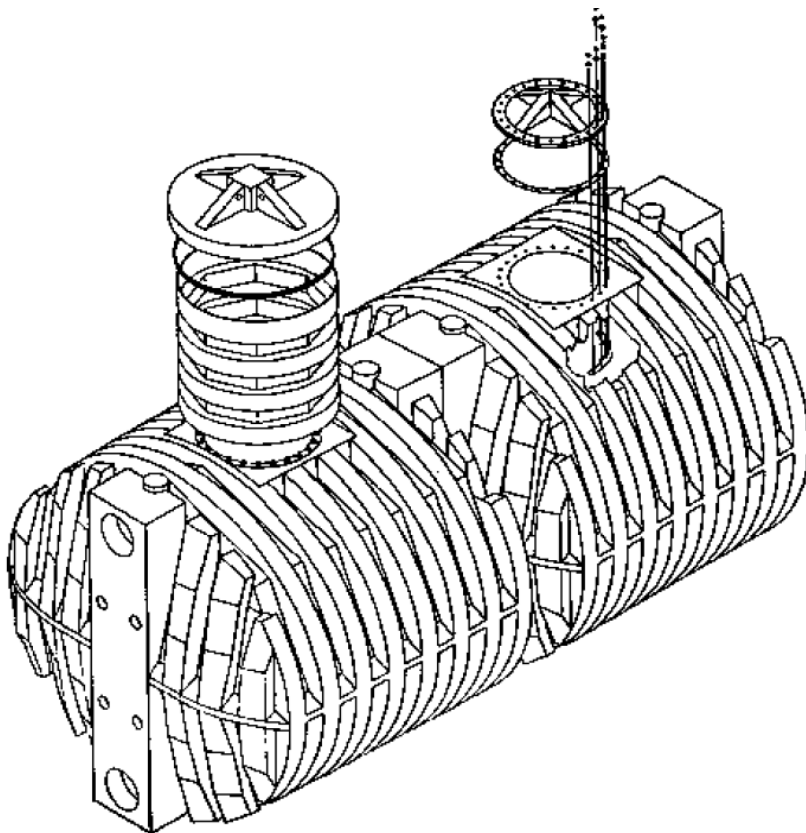
The bioreactor vessels were inoculated with substrate (i.e., sediment/soil containing selenium-reducing bacteria) during the previous pilot study, and the substrate was re-used for this pilot study. The nutrient amendment system for the DS-7 pilot study consisted of both automated and manual methods.

Use of the automated system was planned from spring through fall. The automated feeder consisted of a nutrient holding tank, a dosing pump, a dosing pump controller, and a battery/solar panel power supply. The holding tank was constructed of polyethylene and the organic substrate/nutrient level could be observed without opening the vessel. The dosing pump was intended to provide the required amendment volume based on the demand of the system and on effluent water quality. However, early in the study, the automated feeder plugged and amendments were subsequently added manually.

Liquid or solid nutrients plus other amendments (e.g., zero-valent iron) were manually poured directly into the bioreactor vessels via the manhole access hatches. Operators used the oxidation-reduction condition and the dissolved oxygen concentration in the effluent to identify what, if any, additional amendments were needed to restore optimum bioreactor conditions.

### 3.1.4 Bioreactors

The bioreactor vessels were constructed of polyethylene with a combined volume of 4,000 gallons (2,000 gallons each) and were plumbed in series (Figure 3-2). Both bioreactors were completely buried with access hatches in manholes at the top (Appendix A, Photos A-8 and A-9). The bioreactor vessels were filled with floating polyethylene bio-rings in mid-July 2013 (Figure 3-3). Bio-rings are inert packing rings designed as a solid support medium for use in treatment applications. Packing rings have a high void space (95 percent) and a large surface area.



**Figure 3-2. Schematic of Bioreactors Connected in Series.**



**Figure 3-3. Photograph of Bio-Rings.**

The bio-rings were used to create a tortuous flow path for water being treated in the bioreactor, and to provide sufficient surface area within the system for the attachment and growth of large populations of selenium-reducing bacteria. Floating packing rings were used to maintain buildup of biological solids and chemical precipitates near the bottom of the vessels where they were joined with a flow-through connection.

## 3.2 System Operation and Maintenance

Operation of the pilot unit began on July 16, 2013 after the packing rings had been installed and the initial dose of nutrients was added to the first reactor. The initial influent flow rate was about 1 gpm, which equated to about a 2-day residence time. The system remained at this residence time until it reached equilibrium with respect to selenium removal effectiveness, and sufficient information at this hydraulic residence time had been acquired.

### 3.2.1 Nutrients and Amendments

During the initial startup phase of the pilot study, nutrients were batch fed to the bioreactors to initiate and maintain anaerobic conditions. A target pH of 6 to 8 was set to decrease the potential for production of hydrogen sulfide ( $H_2S$ ) and hydrogen selenide ( $H_2Se$ ). Anaerobic conditions were monitored by measuring the dissolved oxygen concentration in the effluent. The nutrient dosage rate during start-up was relatively high to facilitate new bacterial growth within the bioreactors. Initially, the nutrient added was powdered molasses. When powdered molasses was no longer available locally, pelletized sugar beet pulp was used as a nutrient. Table 3-1 provides a summary of the nutrients and amendments added to the bioreactors over the course of the pilot study.

In mid-September 2013, an automated feeder system was installed in the first bioreactor. The timer was set for the feeder to run for 9 seconds at a time, 4 times per day, adding 24 pounds of molasses to the bioreactor vessel per week. The daily amendment dosage was adjusted periodically based on effluent water quality. The nutrient dosage rate was optimized based on the influent flow rate and water temperature within the pilot system. The original plan was to shut off and drain the automated dosing system before winter began; however, the automated feeder frequently became plugged when condensation caused the molasses or beet pulp to harden. In August, September, and October 2013, amendments were added manually while the feeder was plugged. The automated dosing system was permanently shut down in November 2013 and manual dosing was used thereafter.

Manual dosing consisted of adding solid nutrients on a monthly or twice per month frequency. In response to lower water temperatures and decreased biological activity in the winter, feed rates and influent flow rates were decreased as needed to maintain anaerobic conditions. During the November 2013 dosing, a layer of ice on top of the water in the bioreactors prevented the beet pellets from reaching the water. In January 2014, the water in the bioreactors remained frozen and beet pulp pellets were poured on top of the ice. A thermal blanket was installed over the tops of both bioreactors to melt the ice. Photo A-11, taken in January 2014, shows the pilot treatment system covered in snow. Although the water in the bioreactors was frozen, the seep remains flowing all winter (Photo A-12). When the pilot unit was revisited in March 2014, the ice was broken up and the beet pellets were knocked into the water. The thermal blanket was

reinstalled on top of the bioreactors and remained until the end of April 2014. Manual dosing continued throughout the summer and fall of 2014. In November 2014, the bioreactors were covered with a thermal blanket and were not fed until spring. Manual dosing resumed in April and continued through August 2015. Photo A-13 shows the bio-rings in the bioreactor. As specified in the Pilot Study Work Plan/SAP (Formation 2011b), zero-valent iron (Photo A-14, Appendix A) was added as an amendment to the pilot treatment system in June 2015.

### **3.2.2 Testing of Treatment Chemicals**

Solid samples of zero-valent iron and powdered molasses were collected for laboratory analysis on August 1, 2013, and a sample of pelletized sugar beet pulp was shipped to the laboratory on September 12. One additional zero-valent iron sample was collected for laboratory on September 19, 2013. Samples were analyzed for organic matter, total organic carbon, and the metals, metalloids, and inorganic parameters specified in the Pilot Study Work Plan/SAP (Table 3-2, Formation 2011b). Analytical results are provided in Table 3-2. Both the molasses and the sugar beet pulp contained 65 to 70 percent organic matter. Concentrations of metals, metalloids, and inorganic parameters were relatively low in the molasses and sugar beet pulp. The zero-valent iron, which was used to maintain anaerobic conditions, contained relatively high concentrations of other metals and metalloids including arsenic, manganese, and nickel.

### **3.2.3 Maintenance Activities**

Maintenance activities performed during the initial startup phase of the pilot study included frequently unplugging the automated feeder after condensation caused the molasses and sugar beet pulp to harden. During the operational phase, maintenance involved cleaning the influent and effluent flumes, flushing the inlet pipe, clearing sediment from the transducers, and cleaning and checking the calibration of the sondes. During the winter, flow through the bioreactors was decreased and nutrients were not added. However, maintenance was needed to inspect the influent and effluent valves and install thermal blankets to prevent the water in the bioreactors from freezing. Then, as temperatures warmed, field parameters were evaluated in order to restart the system during high-flow conditions. During spring restart, the valve was opened and the bioreactor vessels were flushed to clear the lines.

## **3.3 Monitoring**

Performance was monitored through routine sampling at two locations (Figure 2-2):

1. Influent water (DS-7-INF)
2. Effluent water (DS-7-EFF)

During the initial startup phase, samples were collected weekly to allow for adjustment of feed rates, and were analyzed for the key laboratory monitoring parameters specified in the Pilot Study Work Plan/SAP (Table 3-2, Formation 2011b). After parameters stabilized, sampling frequency was decreased to twice per month for key parameters, and quarterly for the expanded analyte list (Table 3-3, Pilot Study Work Plan/SAP, Formation 2011b). Field parameters (dissolved oxygen, oxidation-reduction potential, pH, specific conductance, temperature, and turbidity) and flows were measured during sampling events. In addition, oxidation-reduction potential of the effluent was monitored continuously to aid in optimizing the organic substrate/nutrient dosage rate necessary to maintain reducing conditions. These measurements were stored on data loggers and downloaded weekly during the initial phase of the test and monthly thereafter. Additional samples were collected more frequently, as needed, to characterize changes in performance due to treatment system adjustments.

Monitoring of the system included:

- Manual measurement of influent and effluent flow rates and inspections on a weekly basis to verify that there were no leaks in the system (inspections were monthly during the winter shutdown period);
- Continuous measurement of influent and effluent flow rates using instrumentation accessed via the telemetry system;
- Measurement of field parameters and collection of influent and effluent samples monthly for key monitoring parameters and quarterly for the expanded analyte list;
- One-time sample collection of solid amendments added to the system to promote bacterial growth (i.e., powdered molasses, and pelletized sugar beet pulp samples), two-time sample collection of zero-valent iron, and analysis for the monitoring parameters for solid samples; and
- One-time sample collection of bioreactor media (i.e., soil/sediment and packing rings) for toxicity characteristic leaching procedure (TCLP) analysis to complete the pilot study.

Monitoring and sampling results are discussed in Section 4. Analytical data for the pilot study are provided in Appendix B.

### 3.4 Treatment Byproducts

Byproducts of the semi-passive biological treatment system included residual solid organic substrate/nutrients, sludge (solid discharge material), and bioreactor material (packing rings) inside the bioreactor vessels. At the end of the pilot study, the composition of the accumulated material was visually estimated and six samples were collected of these materials to determine disposal requirements and potential contaminant contributions to the system. The material sampled included the remaining organic substrate/nutrient material, sludge, and bioreactor material. Samples were analyzed for the 8 primary Resource Conservation and Recovery Act (RCRA) metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver) using

TCLP. On the basis of the results, treatment byproducts are not characterized as hazardous and can be handled and disposed as solid waste. The material remaining upon completion of the study was left in the bioreactors for use as potential seeding material for any biological treatment system implemented in the future.

### **3.5 Deviations from the Pilot Study Work Plan/SAP**

Deviations from the Pilot Study Work Plan/SAP (Formation 2011b) over the course of the three-year pilot study included the following:

- Flow was not measured in February 2014 because the system was not accessible due to winter conditions.
- Influent and effluent samples were not collected in June 2014 due to problems with flow into the bioreactors. Buildup of organic materials in the system resulted in plugging of flow and fouling of the sondes. Maintenance activities were conducted in June 2014 to address these issues.
- The volume of solids in the bioreactors was not estimated or measured during every sampling event.

None of the deviations had a significant effect on the results of the pilot study.

## **4.0 PILOT STUDY RESULTS**

Influent and effluent water samples were collected from July 2013 through November 2015 and analyzed for selenium and other RI COPCs. This section describes the DQOs and the quality of data collected to support the evaluation of the implementability and effectiveness of the semi-passive biological treatment system. This section also presents the results of the initial startup and operational phases of the pilot study, assesses byproducts of the treatment system, and summarizes the operational parameters, influent and effluent water quality, and selenium removal of the treatment system.

### **4.1 Data Quality Objectives**

Project-specific DQOs identified in the Pilot Study Work Plan/SAP (Formation 2011b) guided the scope of data collection activities conducted for the DS-7 pilot study. The DQOs included the following:

- Evaluate whether the semi-passive biological treatment system is feasible to implement at the Site and can effectively remove selenium (and other COPCs) from seep water; and
- Determine whether or not the semi-passive biological treatment system produces wastes (i.e., accumulated sludge) classified as hazardous.

In order to evaluate the effectiveness of the pilot study, selenium concentrations were measured in the influent and effluent. A statistical test was performed to compare the two sets of selenium concentrations at the 95-percent confidence level and the results are presented in Section 4.6 of this report. The characteristics of treatment byproducts were evaluated by collecting accumulated sludge retained in biosolids in the bioreactor vessels at the end of the pilot study. These materials were analyzed for the 8 RCRA metals, and results were compared to the maximum concentration of contaminants for toxicity characteristic criteria as described in Section 4.5.

On the basis of the results presented in Sections 4.3 through 4.6 of this report, the DQOs identified in the Pilot Study Work Plan/SAP have been met.

### **4.2 Evaluation of Field and Laboratory Data Quality**

The monitoring and data collection activities described in Section 3.3 were designed to address the goals of the DS-7 pilot study and meet the performance and acceptance criteria for use in decision making as specified in the Pilot Study Work Plan/SAP (Formation 2011b). Field QC samples were collected to evaluate the accuracy and reproducibility of field sampling methods.

Laboratory QC samples were collected to ensure the accuracy and precision of laboratory results. Samples collected during the pilot study were submitted to SVL Analytical, Inc. in Kellogg, Idaho, for the analyses specified by the Pilot Study Work Plan/SAP (Formation 2011b). The laboratory data packages for the pilot study were complete and provided the necessary information to allow for verification of data accuracy and assess compliance with specifications for data quality.

Validation of field and laboratory data was conducted by TLI Solutions, Inc. in Golden, Colorado, in accordance with EPA National Functional Guidelines for Inorganic Data Review (EPA 2004), and Guidance for Labeling Externally Validated Laboratory Analytical Data for Superfund Use (EPA 2009a). Qualifiers were assigned to some of the results during the data validation process, and those qualifiers are shown in the data tables included with this report. Appendix B presents a complete listing of validated results from the pilot study along with any data validation qualifiers assigned. No data were rejected during the data validation process, and all sample results are considered acceptable for use in the pilot study effectiveness evaluation.

Based on the data quality and qualifiers assigned in the data validation reports, the DS-7 pilot study data have met the project quality objectives, as specified in the Pilot Study Work Plan/SAP (Formation 2011b).

#### **4.3 Initial Startup**

The initial startup of the semi-passive biological treatment system took place from mid-July to mid-August 2013. After the packing rings were installed, two large doses (100 pounds [lbs] each) of powdered molasses were batch fed to the first bioreactor to enhance the growth of selenium-reducing bacteria and accelerate the selenium reduction process (Table 3-1). Subsequent smaller nutrient doses (25 lbs) were batch fed weekly. The auto-feeder was installed in the first bioreactor near the end of this initial phase. The initial flow at the influent flume was about 2 gpm, and flow was lowered to 1 gpm for system startup (Figure 4-1, Table 4-1). Influent flow for the pilot study was generally maintained at 1 gpm through late July 2013, but decreased to as low as 0.5 gpm in early August. Simplot adjusted the influent flow and flow was maintained at about 1.4 gpm for the rest of the startup period. As shown on Table 4-1, flow at the effluent flume mirrored the influent flow during the initial startup phase of the pilot study indicating that there were no leaks in the system.

Field parameters were measured on a daily basis in accordance with the Pilot Study Work Plan/SAP (Formation 2011b), and are provided in Table 4-1. Anaerobic conditions were monitored using dissolved oxygen concentrations in the effluent, which were significantly lower than concentrations in the influent. The oxidation-reduction potential was measured in order to track conditions favorable for selenium reduction. Negative oxidation-reduction potential measurements of effluent water indicated that the bioreactors had achieved reducing conditions.

The pH results were within the target range of 6 to 8, which decreased the potential for production of hydrogen sulfide ( $H_2S$ ) and hydrogen selenide ( $H_2Se$ ). Water temperatures were maintained at approximately 14 degrees Celsius ( $^{\circ}C$ ). Water samples were collected from influent and effluent measurement systems on July 31, 2013. Total selenium concentrations were 2.17 mg/L and 1.34 mg/L in the influent and effluent, respectively (Table 4-2). Dissolved concentrations were similar. Some selenium removal (38 percent) occurred within the bioreactors during the initial startup phase (Table 4-2).

#### **4.4 Operational Phase**

The operational phase of the pilot study, which took place from mid-August 2013 through mid-November 2015, can be divided into three subphases on the basis of weather conditions and activities related to the treatment system: (1) operation/maintenance during the summer and fall, when selenium removal was most effective, (2) cold weather shutdown during the winter months, when monitoring was dependent on access, water temperature, and relative biological activity, and (3) spring restart, when warming of ambient and water temperatures and increased biological activity occurred. Total selenium concentrations in the DS-7 treatment system influent and effluent are shown by operational phase on Figure 4-2, and results are described in the following subsections.

##### **4.4.1 Summer and Fall Operation/Maintenance**

The initial operation/maintenance subphase took place from mid-August through November 2013. Nutrients/amendments (molasses initially and then sugar beet pulp) were batch fed to the bioreactor at least weekly through September and then monthly through the fall. Field parameters were measured and influent and effluent samples were collected weekly. Influent and effluent flows ranged from approximately 1 to 1.4 gpm. Influent water temperatures averaged  $13^{\circ}C$  during the summer and early fall of 2013 (Table 4-1). Water temperatures began dropping in October and were down to  $6^{\circ}C$  by November. Total selenium concentrations ranged from 0.941 to 1.64 mg/L in the influent and 0.344 to 0.683 mg/L in the effluent (Figure 4-2, Table 4-2). The decrease in total selenium concentrations from influent to effluent ranged from 58 to 65 percent (Table 4-2). Dissolved selenium concentrations were lower than total concentrations, and ranged from 0.788 to 1.55 mg/L in the influent and 0.0868 to 0.373 mg/L in the effluent. A higher percentage of selenium was in the dissolved form in the influent than in the effluent; this also held true for the second and third operation/maintenance subphases discussed below. The percent removal for dissolved selenium was higher and ranged from 71 to 95 percent.

The second operation/maintenance subphase took place from July to November 2014. Sugar beet pulp was batch fed to the bioreactor about once every 3 to 4 weeks. Field parameters were measured, and influent and effluent samples were collected twice per month. Influent and effluent flows were about 1 gpm until mid-October, and decreased to 0.5 gpm thereafter.

Influent water temperatures averaged 12°C during the summer and early fall, but dropped to 3°C by mid-November (Table 4-1). Total selenium concentrations ranged from 1.22 to 3.26 mg/L in the influent and 0.0758 to 0.192 mg/L in the effluent (Figure 4-2, Table 4-2). The decrease in concentration from influent to effluent ranged from 64 to 80 percent for total selenium and 71 to 95 percent for dissolved selenium (Table 4-2).

The third operation/maintenance subphase took place from July to November 2015. Sugar beet pulp was batch fed to the bioreactor three times in July and August. Field parameters were measured, and influent and effluent samples were collected twice per month. Influent and effluent flows were approximately 1.8 gpm. Water temperatures averaged 13°C during the summer and early fall, but dropped to 6°C by early November 2015 (Table 4-1). Total selenium concentrations ranged from 2.13 to 3.92 mg/L in the influent and 0.0454 to 1.34 mg/L in the effluent (Figure 4-2, Table 4-2). The decrease in total selenium concentrations from influent to effluent ranged from 53 to 99 percent (Table 4-2). The percent removal for dissolved selenium was similar and ranged from 51 to 99 percent.

#### 4.4.2 Cold Weather Shutdown

During the first winter of the pilot study, from December 2013 through March 2014, the treatment system was monitored and beet pulp was added even during the coldest temperatures when ice had formed on top of the water in the bioreactors. Field parameters were measured and samples of treatment system influent and effluent water were collected monthly, except when snow prevented access. Influent and effluent flows ranged from approximately 0.7 to 1 gpm and influent water temperatures ranged from 3°C to 5°C (Table 4-1). Total selenium concentrations were 0.833 mg/L and 0.301 mg/L in early winter (influent and effluent, respectively) and 1 mg/L and 0.787 mg/L in late winter (influent and effluent, respectively) (Figure 4-2, Table 4-2). The decrease in total selenium concentrations from influent to effluent was approximately 65 percent, but dipped to approximately 20 percent in late winter as bacterial activity slowed. The percent removal for dissolved selenium was slightly higher at 76 to 81 percent, but also decreased in March (26 percent). As can be seen in Table 4-2, selenium removal is more efficient at higher temperatures.

During winter of the second year, from November 2014 through March 2015, data collection efforts were decreased. Field parameters were measured and one sample was collected during the cold weather shutdown. The influent water temperature reached a low of 4°C in February 2015 (Table 4-1). In response to lower water temperatures and decreased biological activity, flows were decreased to about 0.5 gpm and the system was not fed over the winter. Total selenium concentrations were 0.976 mg/L and 0.89 mg/L in the influent and effluent, respectively (Figure 4-2, Table 4-2). As a result of the lower temperatures and the length of time that the system operated without feeding, the removal of total selenium was only 9 percent and removal of dissolved selenium was 23 percent (Table 4-2).

During winter of the third year, field parameters were measured and one sample was collected at the onset of colder conditions in November 2015. Influent and effluent flows were still at 1.8 gpm but the water temperature had dropped to about 9°C (Table 4-1). Total selenium concentrations were 2.13 mg/L and 0.878 mg/L in the influent and effluent, respectively (Figure 4-2, Table 4-2). Total and dissolved selenium concentrations were decreased by 59 and 58 percent, respectively (Table 4-2).

#### 4.4.3 Spring Restart

In spring 2014, delays in getting the treatment system cleaned and back in full service resulted in little data collection to evaluate system requirements after the cold weather shutdown. In addition, decreased performance of the system during spring restart resulted from buildup of organic materials that decreased or eliminated flow and fouled the sondes. Maintenance was required to clean the sondes and reset the flow through the bioreactors. Field parameters were measured and two samples were collected during spring restart. The influent flow was measured at 1.8 gpm and the water temperature had risen to 13°C (Table 4-1). In late April, the Smoky Canyon Mine received more than an inch of rain in less than a week (measured at the guard shack), which explains the increased flow at the influent measured during sample collection on April 29, 2014 (Figure 4-1).<sup>1</sup> Total selenium concentrations were 4.96 to 5.26 mg/L in the influent and 3.69 to 4.7 mg/L in the effluent (Figure 4-2 and Table 4-2). The decrease in total selenium concentrations ranged from 5 to 30 percent (Table 4-2). The percent removal for dissolved selenium was slightly higher and ranged from 17 to 29 percent.

In spring 2015, with the warming of ambient and water temperatures and a resultant increase in biological activity, nutrient feed rates were adjusted to optimize removal of selenium. Additional maintenance and data collection were performed to evaluate system requirements after the extended cold weather shutdown over the second winter of the pilot study. In addition, one large dose (100 lbs) of zero-valent iron (Table 3-1) was added to each bioreactor in June 2015 as specified in the Pilot study Work Plan/SAP (Formation 2011b) to enhance chemical and microbial reduction of selenium. It does not appear that the zero-valent iron enhanced selenium removal. The influent flow ranged from 1 to 1.8 gpm and the water temperature ranged from 6°C to 14°C (Table 4-1). Total selenium concentrations ranged from 2.11 to 5.31 mg/L in the influent and 0.62 to 1.27 mg/L in the effluent (Figure 4-2 and Table 4-2). The decrease in concentration from influent to effluent ranged from 64 to 86 percent for total selenium and 76 to 97 percent for dissolved selenium (Table 4-2).

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<sup>1</sup> [http://rma.nacse.org/documents/PRISM\\_datasets.pdf](http://rma.nacse.org/documents/PRISM_datasets.pdf)

#### **4.5 Characterization and Assessment of Treatment Byproducts**

The semi-passive biological treatment technology pilot study was concluded with sampling of the bioreactor materials on June 16, 2016. Characterization and assessment of treatment byproducts (organic substrate/nutrients, sludge, and biosolids within the bioreactors) involved estimating the relative amount of these materials remaining in the bioreactors, and collecting and analyzing samples in order to determine appropriate disposal requirements.

At the end of the pilot study, both of the bioreactors were nearly full with little to no void space at the top. Simplot was unable to determine the change in volume of biosolids over the course of the study. The initial volume of material added to the bioreactors is unknown. During the pilot study, substantial amounts of nutrients and amendments were added making it difficult to compare initial volumes to final volumes. Based on a visual estimate, the material within the bioreactors was composed of approximately 8 percent biosolids (packing rings), 10 percent substrate/nutrients, and 10 percent sludge. The remaining 72 percent was liquid. The bioreactors provided an adequate volume of biosolids for treatment over the life of the pilot study (3 years) and were not at capacity at the end of the study, which indicates that the biosolids may be able to sustain a service life of at least 5 years before the media would need to be changed out.

Treatment byproducts (organic substrate/nutrients, sludge, and biosolids inside the bioreactors) were assessed to determine disposal requirements and the potential contaminant contributions to the system. Samples of the treatment byproducts were analyzed for the 8 RCRA metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver) using TCLP and the results are presented in Table 4-3. Selenium was detected in the substrate/nutrient material sampled from the first bioreactor (0.331 mg/L) and in the solid material/sludge sampled from the effluent discharge (0.016 mg/L). TCLP results for the solid materials in the bioreactors were all lower than the corresponding regulatory limit (EPA 1994), which means that these materials can be handled and disposed as non-hazardous solid waste.

#### **4.6 Pilot Study Summary**

Data collected to support the pilot study objectives included operation and maintenance parameters, characteristics of and disposal requirements for treatment byproducts, treated effluent water quality, and overall effectiveness of the treatment system for selenium removal. A summary of these data is provided in the following subsections.

#### 4.6.1 Operation and Maintenance Parameters

Operation and maintenance parameters were monitored and adjusted during the course of the pilot study, resulting in the following observations:

- Influent flow to the treatment system was maintained at a flow rate of about 1 gpm during the summer and fall operation/maintenance subphase (Figure 4-1), which equated to about a 2-day residence time. In response to lower water temperatures and decreased biological activity over the winter, flows were decreased to about 0.5 gpm in late fall and remained there until the system was restarted in the spring.
- Ambient air and water temperatures affect the rate of metabolic activity and, as a result, selenium removal is more efficient at higher temperatures during summer and fall than at lower temperatures during winter and spring. As shown on Figure 4-3, the plot depicting the percent selenium removed mirrors the plot of influent and effluent temperature. The temperature remained about the same in the effluent as in the influent (Table 4-4).
- The pH was maintained within the target range of 6 to 8 (Table 4-1), which reduced the potential for production of hydrogen sulfide ( $H_2S$ ) and hydrogen selenide ( $H_2Se$ ).
- The dissolved oxygen concentration in the effluent was generally maintained below 1 mg/L because the biological treatment process is anaerobic. There were only a few occasions during which dissolved oxygen in the effluent exceeded 1 mg/L (Figure 4-4, Table 4-4).
- Reducing conditions (negative oxidation-reduction potential) are favorable for selenium removal. Reducing conditions were maintained in the bioreactor effluent by adjusting the nutrient dosage. Increasing the nutrient dosage caused a drop in oxidation-reduction potential. As shown on Table 4-4 and Figure 4-5, the percent of selenium removed is higher when the effluent oxidation-reduction potential measured is below or near zero.
- Large doses of nutrients were added to the bioreactor during the initial startup phase to enhance the growth of selenium-reducing bacteria and accelerate the selenium reduction process (Table 3-1, Table 4-4). Subsequent nutrient doses were smaller. The treatment system can operate for 3 to 6 months over the winter without feeding.
- Zero-valent iron was used as an amendment to maintain anaerobic conditions. The iron did not appear to enhance selenium removal (Table 3-1, Table 4-4).
- The treatment system used nitrogen as a nutrient, as shown by the decrease in nitrate/nitrite as N concentrations in the effluent as compared to the influent (Table 4-4), which is evidence of biological activity in the bioreactor. The treatment system did not use phosphorus or sulfate as nutrients because the concentrations of those analytes were the same in both the influent and effluent.

As discussed in Section 4.5, there are no special disposal requirements for treatment system byproducts because they were characterized as non-hazardous.

#### 4.6.2 Influent and Effluent Water Quality

As shown on Figure 4-2, Figure 4-6, and Figure 4-7, selenium concentrations in influent seep water exhibited a seasonal trend with higher concentrations in the spring and relatively lower concentrations during the warmer, drier summer months. A summary of the influent and effluent water quality data are shown in Table 4-5. These data yield the following observations:

- Total and dissolved selenium concentrations were consistently decreased in the effluent water as compared to the influent water. However, the percent removal for dissolved selenium was higher than the percent removal for total selenium (Table 4-4, Figure 4-6, Figure 4-7), which suggests that some particulate material containing selenium is leaving the treatment system in the effluent.
- Other constituents that were clearly decreased in concentration were nitrate/nitrite as N; total and dissolved antimony, cadmium, chromium, nickel, thallium, vanadium, and zinc; and total aluminum, arsenic, copper, and lead. The nitrate/nitrite as N is likely being used as a nutrient and is evidence of biological activity in the treatment system (Table 4-4). The other constituents were most likely retained within the bioreactor.
- Constituents that were clearly increased by the treatment process were dissolved potassium, total and dissolved iron, and total organic carbon. Potassium and total organic carbon most likely originated from the molasses and/or sugar beet pulp used to sustain the microbial population in the bioreactors. Total and dissolved iron most likely came from the zero-valent iron added to the system as a reductant.
- Effluent selenium concentrations generally exceeded the surface water standard (0.005 mg/L); however, the seep water does not discharge to surface water.

#### 4.6.3 Selenium Removal

In order to determine whether the semi-passive biological treatment system can effectively remove selenium from high-concentration seep waters, selenium concentrations in influent water from seep DS-7 and in treated effluent were evaluated using statistical methods (EPA 2009b). The null and alternate hypotheses for the decision rule for evaluating the effectiveness of the treatment system are:

- **Null Hypothesis:** If after implementation of the semi-passive biological treatment system pilot study, selenium concentrations in the effluent water relative to the influent water either increase or remain the same, then the treatment system is not effective in removing selenium from DS-7 seep water or from other Site seep water.
- **Alternate Hypothesis:** Alternatively, if after implementation of the semi-passive biological treatment system pilot study, selenium concentrations in the effluent water relative to the influent water decrease, then the treatment system is effective in removing selenium from DS-7 seep water and is likely effective in removing selenium from other Site seep water.

Data sets for statistical evaluation were compiled from the July 2013 through November 2015 pilot study data; one for influent data and the other for effluent data. Each data set was tested for normality to determine the data distribution type and select an appropriate comparison test procedure (parametric vs. non-parametric). The Shapiro-Wilk test for normality was performed at the 95-percent confidence level and the results of the tests for normality are reported in Appendix C.<sup>2</sup> Neither the influent (DS7\_INF) nor the effluent (DS7\_EFF) data set was normally distributed; therefore, a non-parametric comparison test, the Wilcoxon rank-sum test, was performed as a two-sample comparison test at the 95-percent confidence level.<sup>3</sup> The result of the two-sample comparison test is reported in Appendix C. Because the comparison test indicated that statistically significant decreases in selenium concentrations were observed in the effluent compared to the influent, the conclusion of the pilot study is that the semi-passive biological treatment system is effective in removing selenium from DS-7 seep water and would likely be effective in removing selenium from other Site seep water as well.

As shown in Table 4-2, Figure 4-6, and Figure 4-7, the percent removal for dissolved selenium is nearly always higher than the percent removal for total selenium. Table 4-2 also shows that the ratio of dissolved to total selenium in the influent averages 97 to 100 percent, which indicates that all of the selenium in the influent when it enters the treatment system is in solution. By contrast, the ratio of dissolved to total selenium in the effluent averages 50 to 75 percent (excluding data from the initial startup phase) which indicates that the effluent discharged from the treatment system contains selenium in particulate matter. The treatment system converts dissolved selenium to total selenium, which is then trapped as precipitated particulates on the bioreactor media. As is evident from the total selenium concentrations in the effluent, not all of the particulates are trapped in the bioreactor – some are released in the effluent.

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<sup>2</sup> Refer to EPA Unified Guidance (EPA 2009b) Section 10.5.

<sup>3</sup> EPA Unified Guidance (EPA 2009b) Section 16.2.

## 5.0 SUMMARY AND CONCLUSIONS

This report describes the implementation and results of a water treatment pilot study conducted by Simplot using a semi-passive biological treatment process originally developed by the University of Idaho (Möller 2002). The study was performed at the Smoky Canyon Mine at seep DS-7, which flows from the eastern toe of the Panel D external ODA, from July 2013 to November 2015 with final data collection of the bioreactor materials in June 2016. The objectives of this pilot study were to evaluate the effectiveness of the semi-passive biological treatment system for removing selenium, determine operating parameters to provide additional information regarding implementability and cost of the system, and determine the applicability of the technology in contributing to achievement of remedial action objectives eventually developed for the mine.

In summary, the semi-passive biological treatment system is moderately effective for removal of selenium from high-concentration, low-flow seep water. Overall, the treatment system achieved 56 percent removal of total selenium from seep water. Selenium removal was higher in the spring through fall period (72 percent) than in the winter through spring period (47 percent). Effluent concentrations typically ranged from 0.3 to 1 mg/L, and were lower than influent concentrations which typically ranged from 1 to 4 mg/L. Although most of the selenium in the influent is in solution, the effluent discharged from the system does contain a larger proportion of selenium in particulate matter.

The semi-passive biological treatment system is fairly easy to implement and can be installed, operated, and maintained using common materials and local feed source(s), but may need additional supplements to promote bacterial activity. Although the system is semi-passive, it is more difficult to operate during the winter/spring period – there were issues with surface freezing within the bioreactor and difficult access – and additional maintenance (e.g., cleanout or flushing) is needed in the spring after extended periods of minimal maintenance or shutdown over the winter. Byproducts of the treatment system are not hazardous and do not require special disposal.

The capital cost for construction of a new 6 gpm system, including materials, equipment, and labor for installation of the bioreactors and flow lines required for implementation of the biological treatment system, is approximately \$220,000 (refer to Appendix D for the DS-7 Cost Estimate). Operation and maintenance costs are approximately \$20,000 per year and include nutrients and amendments (for feeding the treatment system), materials, equipment, labor, and monitoring (Table D-1). A present value analysis (Table D-2, Appendix D), shows the total present value for a 30-year project life of approximately \$550,000.

In conclusion, the semi-passive biological treatment system is a remedial technology process option that could be considered in the FS for the Smoky Canyon Mine. The treatment technology would not be effective at locations that discharge to regulated streams that support aquatic life, because the treated effluent would need to consistently meet the surface water benchmark for selenium of 0.005 mg/L. However, the treatment technology could be effective for ODA seeps, where moderate removal of selenium (rather than meeting the surface water standard) is an appropriate goal; the pilot system removed 56 percent of total selenium on an average annual basis.

The design of the treatment system would need to consider problems identified in this pilot study, such as decreased retention of particulate selenium, decreased performance in winter due to freezing within the bioreactors, and difficult access (to adjust operational parameters). The semi-passive technology evaluated in this pilot study would require significantly more labor for operation and maintenance than a true passive system. Passive biological treatment systems would require less maintenance and may be more implementable given the access limitations encountered in this remote seep location.

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## TABLES

## FIGURES

**APPENDIX A**  
**Field Photo Log**

**APPENDIX B**  
**Project Analytical Data**  
(on CD)

## **APPENDIX C**

### **Statistical Results**

## **APPENDIX D**

### **Costs**